ShakeCast Introduction

1. Introduction

The rapid and reliable dissemination of detailed earthquake information is of great importance for public safety and emergency response. This information is needed by all kinds of facility owners, such as municipalities, utilities, building managers, schools, and many others. Such organizations would like to be "consumers" of earthquake information, but currently have no simple methodology that they can use to readily access and make use of earthquake information.

The ShakeCast System is designed to be a simple, reliable, and widely deployable software tool that any modestly capable computer user can install on their computer to receive and make use of customized and personalized earthquake information. We call the system ShakeCast (short for "ShakeMap Broadcast") because its purpose is to broadcast ShakeMaps. The information to be disseminated via ShakeCast is the output of the USGS ShakeMap system, which provides early estimates of the severity of shaking during an earthquake and thus is a good tool for estimating the likelihood of damage to structures and societal impact.

The ShakeCast software does much more than simply deliver maps of the areas affected by an earthquake. It will also:

- Automatically receive and process notifications of earthquakes
- Let you define locations (representing structures and facilities) of interest to you, and set shaking thresholds that will trigger automatic notification
- Provide you with electronic notification (pager, email, personal web pages, etc.) of events and projected shaking intensity at facilities you specify
- Reliably manage the receipt of updated shaking data from multiple ShakeCast servers distributed around the Internet, so that you have a excellent chance of receiving an uninterrupted and authenticated data feed even after a major event that disrupts communications
- Easily integrate with in-house GIS systems, control systems, utility outage management systems, and other business systems in your organization
- Provide a mechanism for continual end-to-end testing of the ShakeCast system, so that you can be assured that the system is working properly when you eventually need it

The benefits of the ShakeCast system are substantial:

- ShakeCast allows individuals and facility owners to make widespread and immediate use of the beneficial information already in ShakeMap. ShakeCast takes advantage of the very substantial investment already made in ShakeMap and in the very large seismic monitoring infrastructure behind it.

- The ShakeCast system provides quantitative metrics on the use of ShakeMaps both before and after an earthquake. This data is then available for policy decisions on the future direction of the ShakeMap and ShakeCast systems. The ShakeCast system will return detailed information about these users that will help ShakeMap planners better understand how ShakeMap data is used.
- ShakeCast should help engage and involve managers and policy makers at a wide variety of institutions (e.g., state transportation departments, municipal governments, emergency responders, utilities, etc.) who are concerned about timely receipt of earthquake shaking data.

The next Section of this document provides a brief background discussion on the history and challenges of the broadcast of earthquake information and then describes how the ShakeCast system addresses these issues.

2. Background

Historically, the only objective data about possible damage available immediately after an earthquake has been an early estimate of “location and magnitude". Such a simple metric can easily be broadcast using common communications technologies such as radio, television, email and pagers. For facility managers responsible for geographically dispersed facilities, however, a simple location and magnitude is of limited practical utility because it does not yield a meaningful estimate of the likelihood of damage at each facility with sufficient detail to guide facility managers in their initial emergency response activities.

A much more useful metric of damage likelihood has been devised: a "ShakeMap". This map estimates, with accuracy appropriate for use by ShakeCast consumers (utilities, school districts, municipalities, etc.), the "shaking" (intensity, peak ground acceleration, velocity, and spectral response) that structures were likely subjected to during an earthquake. A ShakeMap provides a good first-order estimate of the likelihood of damage, and when enhanced by data about the structural resilience of facilities (a metric called “fragility”), ShakeMap can provide extremely valuable information to facility owners directing early response to an earthquake.

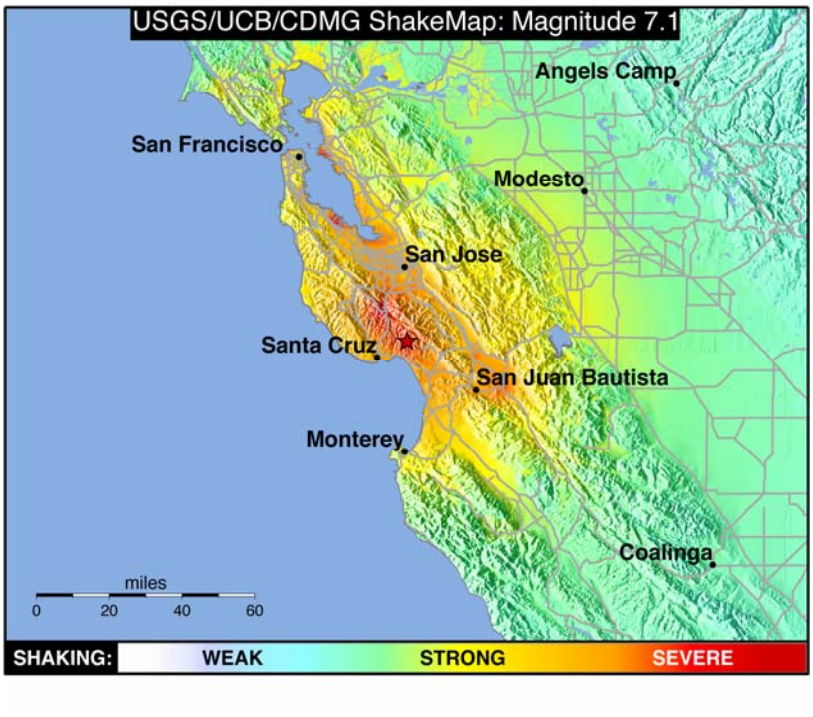
The United States Geological Survey (USGS) has developed an automated system for computing ShakeMaps. This system is now generating ShakeMaps within a few minutes after an earthquake, which is early enough to be of considerable value for emergency response. This system is now operating in four Western regions of the United States (Southern California, Northern California, the Pacific Northwest, and Utah). Other regions may come online in the future.

3. Moving Beyond Location and Magnitude

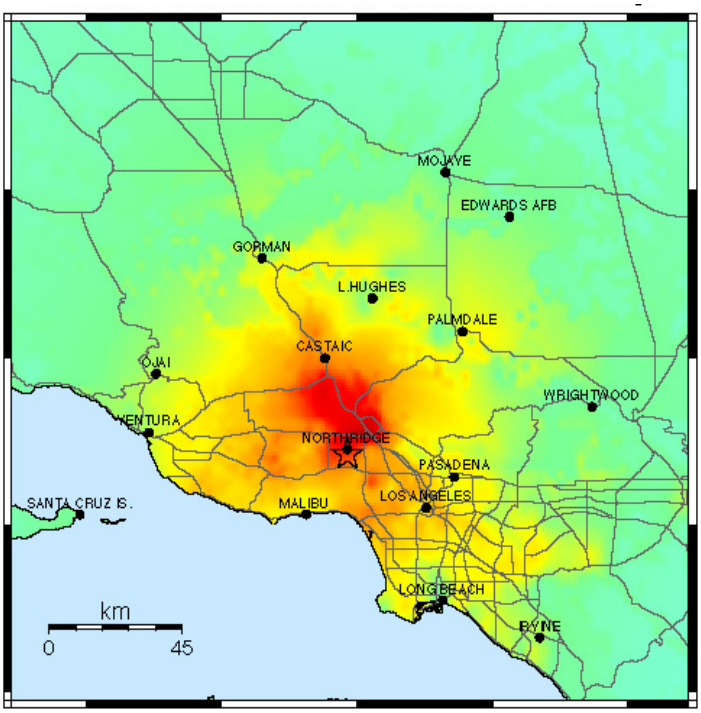
To illustrate the advantages of a ShakeMap over a simple “location and magnitude”, consider the case of two recent earthquakes.

The Loma Prieta earthquake in 1989 caused serious damage and loss of life in the California Bay Area. The figure below shows that earthquake as it would be represented by a simple “location and magnitude” map.

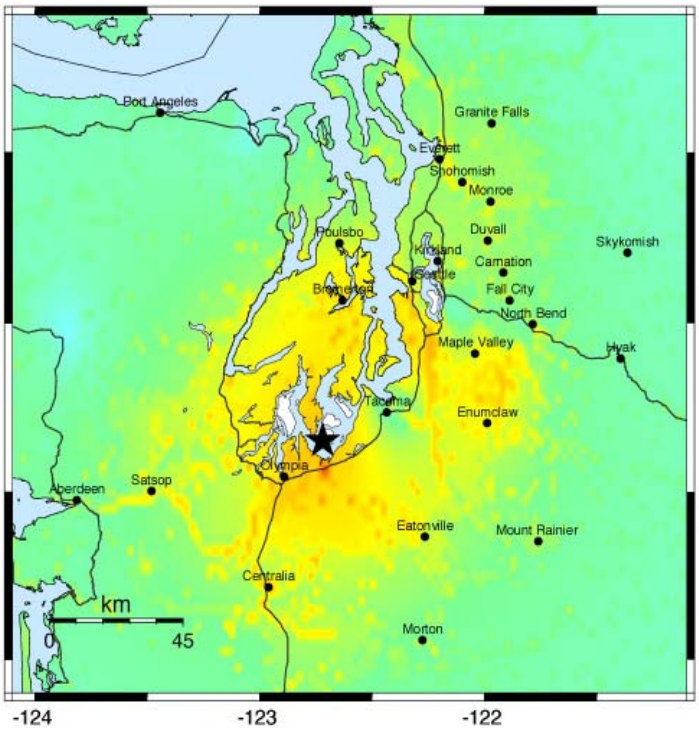
In contrast, consider the map below, which is what ShakeMap would generate were the same earthquake to occur today. The colors represent the degree of shaking experienced at each point on the map. Note especially the red areas in the San Francisco Bay Area, many miles from the epicenter of the earthquake. This information about these distant areas with severe shaking is simply lost in the diagram above.



Not only can the location of potential damage be misleading in a simple "location and magnitude" report, but the severity of damage may also be misrepresented. Consider the following two Shakemaps showing the severity of shaking from similarly-sized events. Although the events have essentially the same "magnitude", the severity of actual shaking (and thus the potential for damage) are quite different in the two cases. (As in the previous figure, the red color indicates more severe shaking).



Magnitude 6.7 Northridge, CA



Magnitude 6.8 Nisqually, WA

4. Disseminating Earthquake Information

Once people know an earthquake has occurred, they can visit the ShakeMap web sites to obtain maps and data. However, few organizations have the technical means use this data other than by "just looking at it". Although a few companies have in the past received a "push" of ShakeMap data, there was not a reliable dissemination method for promptly broadcasting this data to the many thousands of individuals and organizations that need it. Nor is the information readily available in a form that those individuals and organizations can easily use.

Disseminating earthquake shaking information is a difficult problem, for a variety of technical reasons:

- Wide adoption of such a system will depend upon reliable transmission of data, even if communications networks have been damaged.

- There is a wide variety of data products that must be delivered for different users, including different metrics of shaking intensity (e.g., peak acceleration, velocity, etc.).
- The spatial variability of shaking intensity is critical, and most consumers of the data are likely interested only in data for specific locations where they own or manage facilities that might be damaged by earthquake shaking.
- There are difficult technical problems with triggering and alarms, to ensure that the proper people and systems are notified when specific events occur but that false alarms do not occur.
- It is important to ensure the authenticity of the earthquake data, so that organizations making operational decisions can be certain that the information came from a reliable source.
- It is important to keep track of updated versions of each data product so that as new information arrives it can be seamlessly related back to the original event and previous version of the data and to decisions that may have been made based on the prior data.
- There are important issues of event timing and timeliness, and it is critical that data from multiple sources relating to the same event or closely related events (e.g., aftershocks) be properly correlated.
- There is wide variance in the types, sophistication, and purposes of the organizations and computer systems that will consume the data.

Further major complications center on the infrequency of events. Historically, earthquake-related automated systems have not functioned flawlessly, because earthquakes are very infrequent, widely distributed, and extremely variable in their mechanism and damage characteristics. It is a significant technical challenge to build a network of interacting computer systems that is guaranteed to function when an earthquake actually happens. The system must be robust enough to "set it and forget it," possibly for years, yet flexible enough and simple enough to manage so that new data products and tools can be added without impacting reliability.

5. ShakeCast Software Design Philosophy

Fortunately, there exists in the Internet community most of the software tools and protocols for building a robust system that meets the technical requirements of an earthquake information dissemination system. What is required is small amount of new software, a software framework for the broadcast of ShakeMaps, and set of protocols that defines how the system utilizes already-available Internet tools. These elements can then be implemented in an open source software system that can be easily installed by any modestly capable system administrator, and easily extended and customized for local applications by any developer with a modest knowledge of current Internet tools.

The design of ShakeCast takes full advantage of the software tools that are widely available and commonly used on the Internet. The ShakeCast system is intended as not a final software solution to be used identically by every site, but as a reference

implementation: working software that others can either use or extend as they wish. The reference implementation is freely downloadable and will perform all of the basic functions needed by a consumer of earthquake shaking data, including:

- Automated notification (email, pager, etc.) of excessive "shaking" (using various definitions) at a list of specific locations
- Notification regarding events of various kinds internal to the ShakeCast system, including system activity above a specified threshold or failure of internal test procedures
- Reliable, coordinated, and non-duplicated receipt of data from multiple sources
- "Hooks" to incorporate this data in other corporate information systems, such as GIS systems, control systems, internal alarm systems, and the like
- Simple installation on Windows NT/2000/XP, FreeBSD, and other operating systems
- A robust quality assurance system that continually verifies that the entire ShakeCast system is functioning correctly end-to-end
- A complete system of usage monitoring, logging, and reporting, so that the administrators of individual ShakeCast receivers and the administrators of the ShakeCast servers will be able to assess how and how much ShakeMaps are being used.

Our design goal for the ShakeCast reference implementation is that a modestly knowledgeable personal computer user or UNIX system administrator can install the entire system and begin receiving useful, reliable, authenticated, location-specific reports of earthquake shaking with a few hours of effort.

A further goal is to create a community of software developers who work for enterprises who are consumers of ShakeMap data. This community of developers will then be able to continue enhancement and extension of ShakeCast so that ShakeMap information can be made more readily usable by their organizations.

6. ShakeCast Users

ShakeCast software is designed to be easy to install and configure, and will run on a wide variety of computer systems. It is intended for a wide variety of user organizations:

- *Public Utilities* may use ShakeCast to generate alarms indicating possible impacted facilities and to direct initial response and post-earthquake inspection efforts.
- *Public Safety Agencies* may use ShakeCast to help plan the deployment of emergency resources
- *Property Mangers* will use ShakeCast to prioritize the dispatch of inspection and repair personnel to their properties
- *Individuals* will use ShakeCast to ascertain the likelihood of damage or possible injury to loved ones, homes, or property

7. Technical Features of the ShakeCast Software System

The following tables and figures briefly describe some of the important technical features and design elements of the ShakeCast software and protocols.

ShakeCast Server Software Features	
Feature	**Description**
Multi-platform	Available on PCs and UNIX systems
Easy installation and configuration	Installation and basic configuration in an hour or two
Software registration	Software registration with ShakeCast broadcast systems
Integrated quality assurance and testing	The ShakeCast software will participate in the ShakeCast system's comprehensive end-to-end testing procedures to provide high confidence in proper system function during an earthquake. Broadcast data will be checked for authenticity, correctness and completeness.
Automated notification	The system will notify a list of people of earthquake-related events via email, pager, and other mechanisms. Notification can be based on shaking intensity (e.g., "peak ground acceleration at Mom's house greater than 0.3g") using any of the shaking metrics of the current or future ShakeMap system. Notification can also be based on structure fragility (e.g., "notify me if there is probable damage at any of the following fifty electrical substations"). Users can "sign up" for notification via a Web page on their local ShakeCast system.
Local web pages	Provide local ShakeCast users the ability to view shaking data (including maps, events, and alarms) on web pages served from their local ShakeCast server without each user needing to access the main USGS ShakeMap systems.
Data version support	Revise and re-issue notifications as new data arrives. Maintain a permanent record of the sequence of messages and notifications issued to aid in post-event analysis.
Locations and thresholds database	Maintain a local list of locations of interest and notification thresholds.
External program integration	ShakeCast can trigger the execution of external programs for further event and data processing.
Simple administration	Web-based configuration and administration interfaces
High quality documentation	Professionally-developed documentation and support materials

System Reliability Features	
Feature	**Description**
Support ShakeCast from multiple servers	Protocol and tools will efficiently use multiple simultaneous broadcast servers. Each ShakeCast system can sign up with multiple servers on different networks to improve the likelihood of

	successful event notification and data delivery. ShakeCast systems will efficiently use multiple servers, improving response-time for all ShakeCast users.
Cascading servers	ShakeCast servers can be cascaded (a tree of servers) to improve scalability and reliability. For example, a primary corporate server can be configured to feed multiple internal ShakeCast systems, or a central State server can be configured to feed departmental servers in many departments or regions.
Integrated quality assurance and testing	ShakeCast software can participate in frequent end-to-end system tests, report errors to the local system administrator, and will log error types to the ShakeCast developers to aid in designing future software enhancements.
Comprehensive message logging	An integrated and comprehensive message logging and analysis system will aid the local system administrator in tracking system performance.
Support for Application Service Providers (ASPs)	The software will be suitable for customization by Application Service Providers who want to add further value to the system. ShakeCast could also be used by large "portal" sites (e.g., AOL, Yahoo) who want to provide their users with customized earthquake information the same way they currently provide customized weather information.

8. ShakeCast Software Development Plans

This document describes the capabilities of the ShakeCast Reference Implementation. The Reference Implementation is the most basic system that implements the core (required) features of the ShakeCast design. The Reference System is freely available software, in the public domain.

It is hoped that some software developers will take the Reference System and extend it, adding functions that their organization finds necessary or useful. The intent of the ShakeCast Project is to facilitate the development of such software extensions in an Open Source development environment, so that everyone in the extended ShakeCast community can take advantage of each other's efforts.

The sharing of new software is also facilitated by the use of XML (the Extensible Markup Language) to express all ShakeCast metadata. All of the data exchanged in ShakeCast is described and internally documented in XML. By making the ShakeCast data formats easily readable, public, and transparent, and by providing easy to use tools to define these data formats, the ShakeCast project intends to promote the sharing of shaking data products and the tools that operate on these data products.

Software Development Model	
Feature	**Description**
Open source development	Use an open source development model. Encourage shared development by external organizations so that ShakeCast improvements made by one organization can be incorporated back

	into the product.
Web-based transport	ShakeCast communication will be via HTTP, the protocol used by the World Wide Web. By using HTTP, the ShakeCast project will avoid many of the issues surrounding the exchange of information between organizations.
XML-based metadata	ShakeCast will use self-describing data products using XML so that new data types, data formats, and sources can be added easily
Imbedded security and authentication	All external communication includes the potential for adding for public key signatures and manifests.

9. ShakeCast Terms and Terminology

The terminology used in ShakeCast may differ slightly from that used in other information systems.

9.1 ShakeCast Server

A *ShakeCast Server* is a computer that is running the ShakeCast Server Software. The server may or may not be acting as a server in the traditional sense: sending data downstream to another ShakeCast Server. Instead, a server may be only receiving data from another ShakeCast Server and making that data available on the web.

9.2 Upstream and Downstream

ShakeCast machines are more easily defined in terms of being *upstream* or *downstream.* An upstream machine sends ShakeMap data to a downstream machine. The request to send the data may originate on either machine.

9.3 Event

An *event* is a seismic event – an earthquake (either real or simulated). All events have a globally unique and permanent identifying number, called an event ID. The event ID is assigned by the seismic monitoring systems, not by ShakeCast or ShakeMap. Once created, events may not be deleted, although they may be marked as "canceled" to indicate that an event message was anomalous and should no longer be considered.

9.4 ShakeMap and ShakeMaps

ShakeMap is a software system for computing maps of shaking intensity. It uses data from networks of seismometers and other sources to estimate shaking intensity as measured by a variety of physical or instrumental metrics such as peak acceleration, velocity, spectral response, instrumental intensity, and so on. There are very few ShakeMap systems, all of them operated by teams of seismologists and their professional support staffs.

ShakeMap is also the name for the maps produced by the ShakeMap system.

9.5 Exchange

An *exchange* is when one ShakeCast server "talks to" another and sends information. An exchange can be as simple as "Hello, I'm still listening" or as complex as the transfer of a complete set of GIS files for an event.

9.6 Product

A *ShakeMap Product* (or just *Product*) is a result of ShakeMap processing. When ShakeMap processes a seismic event, it produces files and maps for many different metrics (i.e., peak acceleration, velocity, etc.). Each of these maps may be produced in many different data formats (i.e., as a grid of scalar values, as a GIS shapefile, as an image in JPEG format, as an image in PostScript format, etc.).

Each combination of event, metric, and format is a different *product.*

9.7 Product Metric

A *product metric* (sometimes just called a metric) is a measure of shaking such as peak ground acceleration, maximum velocity, and so on. Each metric for an event is provided by one or more different ShakeMap products.

9.8 Facility

A *facility* is a location that is to be monitored by ShakeCast. A facility is typically a building, bridge, highway, or similar man-made structure. The location of the facility must be known so that ShakeCast can attribute various levels of shaking at that location, and the facility may have associated fragility measures in one or more of the shaking metrics.

9.9 Fragility

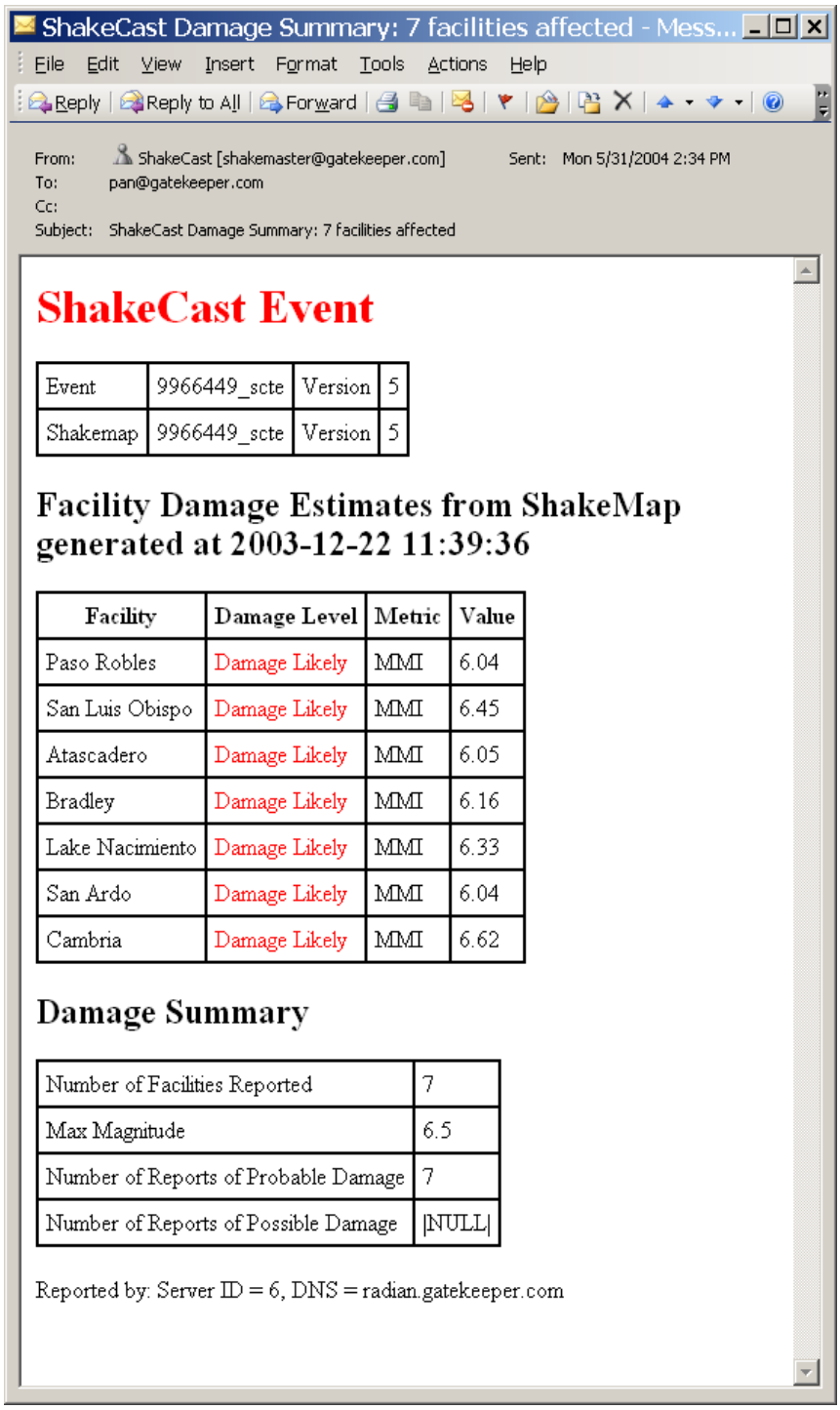
Fragility is the measure of likely damage at a particular facility when a certain level of shaking is exceeded, as measured in a particular metric (e.g., "peak acceleration at the period of one second").

9.10 Damage Level

There are classes of fragility associated with each facility in each metric. The *damage level* is the class or category of shaking intensity experienced at a particular location. Damage levels are typically assigned as "No damage expected", "Some damage expected", and "Damage likely", or "green", "yellow", and "red". Damage levels are locally defined on each ShakeCast Server, and different organizations may use different categories or a different number of categories.

9.11 Notification

Notification is the process of electronically notifying a ShakeCast end user that a particular damage level is estimated at a particular facility from a certain event. Notifications can be delivered in a variety of electronic forms, including as an email message or an electronic pager message. The following figure shows one possible notification format. The format and content of notification messages may be altered by the local ShakeCast system administrator.



ShakeCast Damage Summary: 7 facilities affected - Mess...

File Edit View Insert Format Tools Actions Help

Reply | Reply to All | Forward

From: ShakeCast [shakemaster@gatekeeper.com] Sent: Mon 5/31/2004 2:34 PM
To: pan@gatekeeper.com
Cc:
Subject: ShakeCast Damage Summary: 7 facilities affected

ShakeCast Event

Event	9966449_scte	Version	5
Shakemap	9966449_scte	Version	5

Facility Damage Estimates from ShakeMap generated at 2003-12-22 11:39:36

Facility	Damage Level	Metric	Value
Paso Robles	Damage Likely	MMI	6.04
San Luis Obispo	Damage Likely	MMI	6.45
Atascadero	Damage Likely	MMI	6.05
Bradley	Damage Likely	MMI	6.16
Lake Nacimiento	Damage Likely	MMI	6.33
San Ardo	Damage Likely	MMI	6.04
Cambria	Damage Likely	MMI	6.62

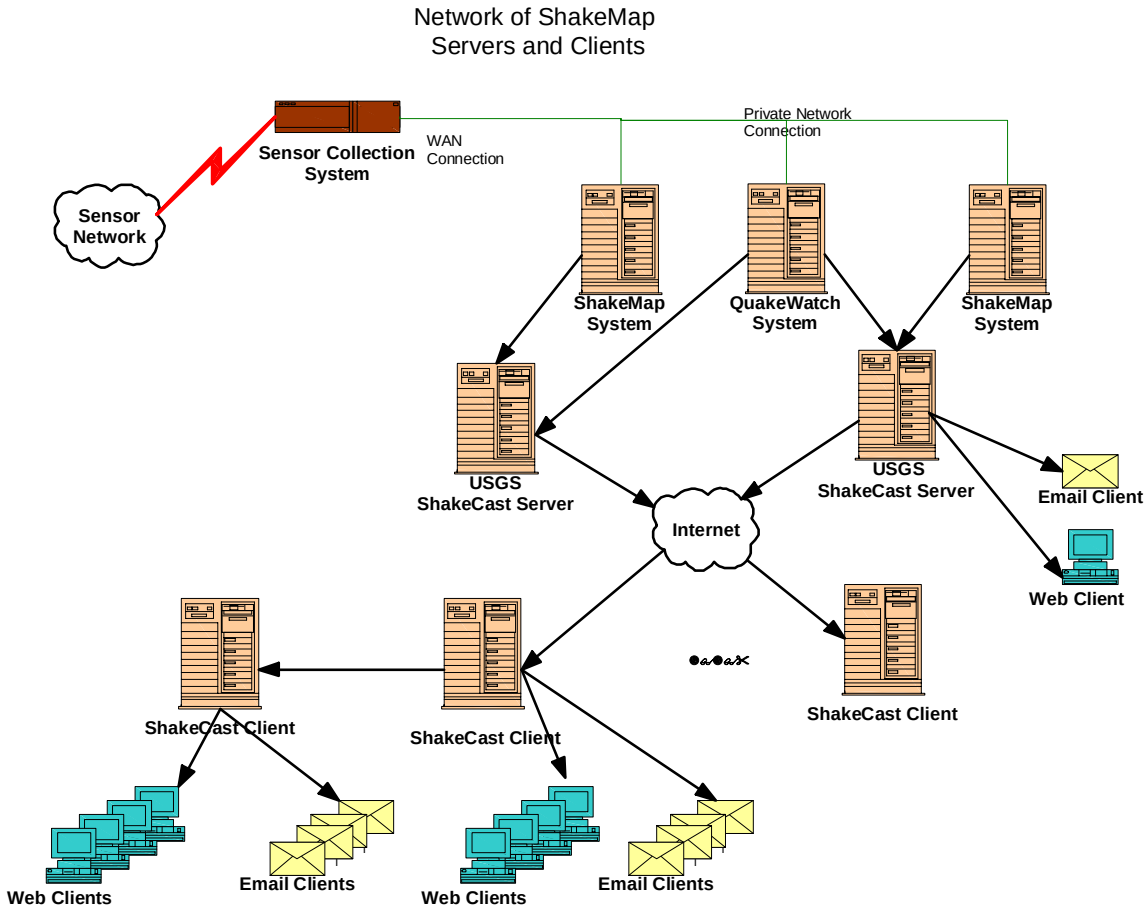
Damage Summary

Number of Facilities Reported	7
Max Magnitude	6.5
Number of Reports of Probable Damage	7
Number of Reports of Possible Damage	|NULL|

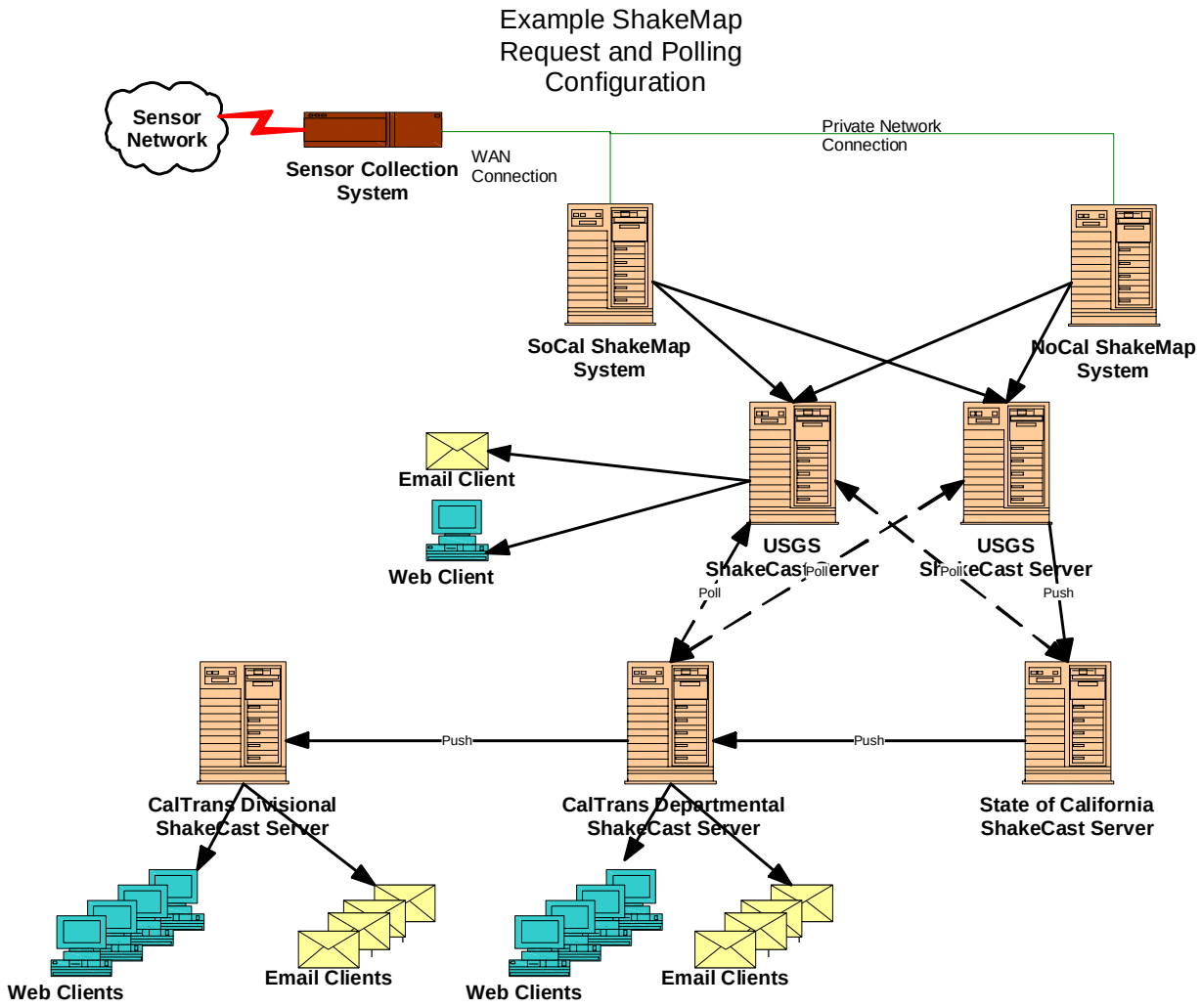
Reported by: Server ID = 6, DNS = radian.gatekeeper.com

10. ShakeCast Network Topology

ShakeCast is may be visualized as a network of interconnected computer systems. The basic structure of the ShakeCast network is shown in the following figure.



ShakeCast servers can be configured to receive unsolicited input of ShakeCast events and products. They may also be configured to periodically poll upstream ShakeCast servers for information. An example configuration showing how servers might be configured for both polling and "push" is shown in the following figure. The figure shows how some servers might be configured to poll for data, some to receive a push of data, and some configured for both. The figure also shows how some servers can be configured to receive data via two or three paths, providing increased protection against failure of upstream servers or of the network connection to those servers.



11. Conclusion

We expect that the ShakeCast System will be a critical future component of the Nation's future earthquake response system.